Robotics

Erwin M. Bakker| LIACS Media Lab

13-3 2023

Universiteit Leiden

Bij ons leer je de wereld kennen

Mobile Robot Challenge

Lecturer:
Dr Erwin M. Bakker (erwin@liacs.nl)
Room 126a and LIACS Media Lab (LML)

Teaching assistant:
Mor Puigventos (email)
TBA (email)

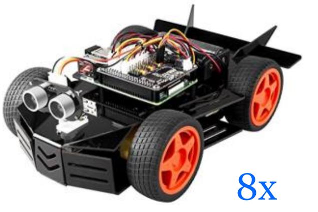
Period: February 6th - May 22nd 2023
Time: Monday 15.15 - 17.00
Place (Rooms):
a) Gorlaeus - Lecture Hall C3
b) Sylvius - 15.31
c) Van Steenis - E0.04
d) Oortgebouw - Sitterzaal

Schedule (tentative, visit regularly):

Date	Room	Subject
6-2	C2	Introduction and Overview
13-2	a	Locomotion and Inverse Kinematics
20-2	b	Robotics Sensors and Image Processing
27-2	a	No class
6-3	c	No class, SLAM Workshop on Brightspace
13-3	a	SLAM + Mobile Robot Challenge Intro
20-3	d	Project Proposals I (by students)
27-3	d	Project Proposals II (Week 13, start 15.30)
3-4	d	Robotics Vision
10-4		No Class (Eastern)
17-4	d	Robotics Reinforcement Learning&Workshop
24-4	d	Project Progress Reports
1-5	d	Mobile Robot Challenge I
8-5	a	Mobile Robot Challenge II
15-5	d	Project Demos I
22-5	d	Project Demos II
29-5		Whit Monday
5-6		Project Deliverables

Website: http://liacs.leidenuniv.nl/~bakkerem2/robotics/

3x



8x

6x

2x

Group Size 4 students

Universiteit Leiden. Bij ons leer je de wereld kennen

SLAM: Simultaneous Localization And Mapping

Mapping

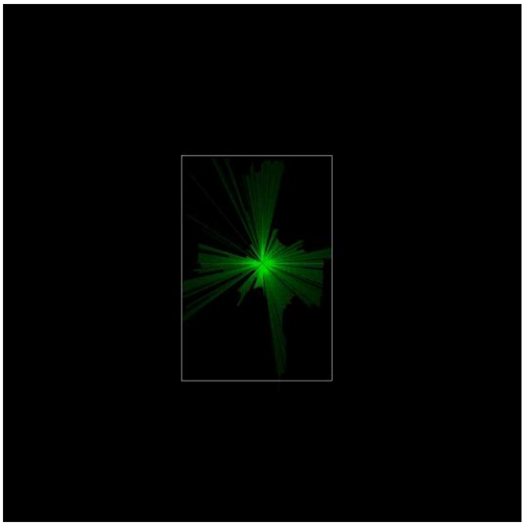
- Use sensor data: US, LIDAR, Camera, Structured Light, etc. to make a map of the environment of the robot.

Localization

- Determine the pose of the robot relative to the map.
- Initial pose can be given: **pose tracking problem**
- No initial pose given: **global localization problem**

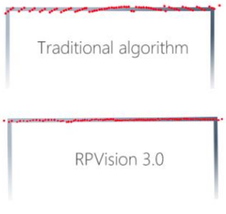
SLAM: do both Mapping and Localization at the same time.

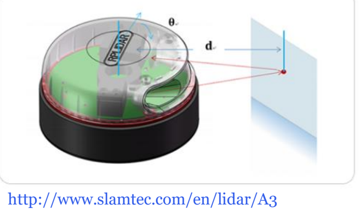
VSLAM: use camera (mono, stereo, multi-, depth, etc.) to solve SLAM



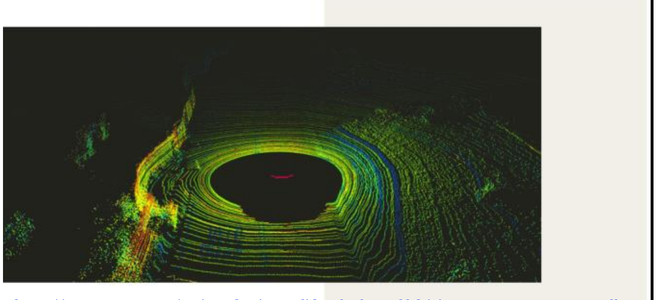
MonsterBorg SLAM by E. van der Zande

LIDAR

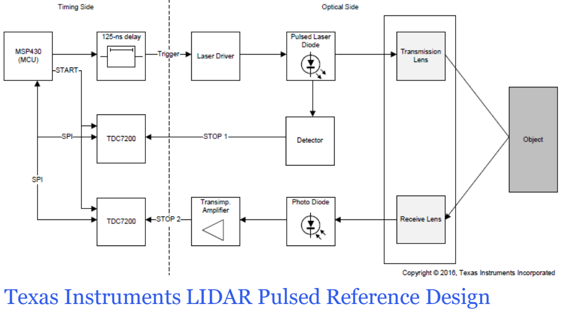




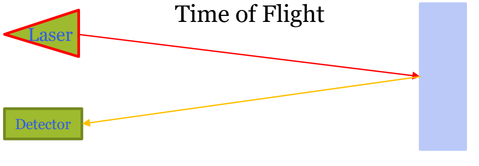
http://www.slamtec.com/en/lidar/A3



https://news.voyage.auto/an-introduction-to-lidar-the-key-self-driving-car-sensor-a7e405590cff



Texas Instruments LIDAR Pulsed Reference Design



- Speed of light ~ 3 x 10^8 m/s
- In 1 picosecond (= 10^{-12} sec) light travels ~ 3 x 10^{-4} m = 0.3 mm
- During 33 picoseconds light travels ~ 1cm

CES2019

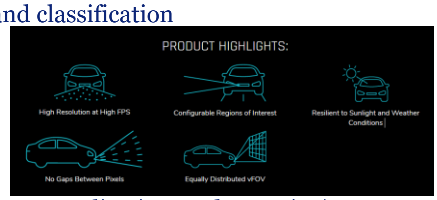
BMW Self Driving Car

InnovizOne Solid-state Lidar (goal: sub $1000 sensor)

- Angular resolution 0.1° x 0.1°
- FOV 120° x 25°
- 25 FPS
- Range 250m

Perception Capabilities

- Object detection and classification
- Lane detection
- Object Tracking
- SLAM



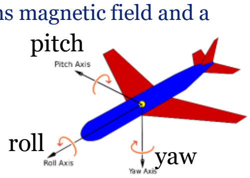
SLAM (Simultaneous Localization And Mapping)

Universiteit Leiden. Bij ons leer je de wereld kennen

IMU, or Inertial Measurement Unit

IMU consist of Sensors for

- orientation, by measuring the earths magnetic field and a gyroscope.
- acceleration,
- (angular) velocity.

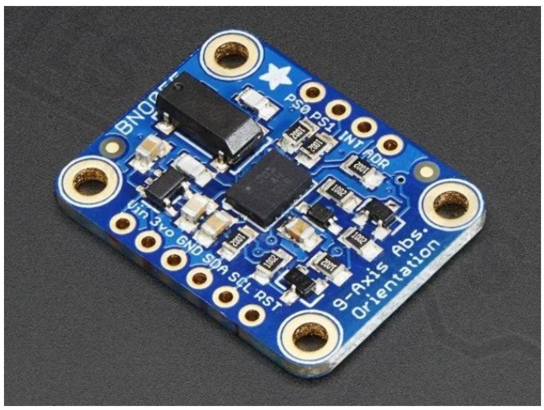


In SLAM

- **Orientation** is very useful for scan matching: a good initial guess.
- **Acceleration** is calculated by subtracting the earth gravity vector from the raw accelerometer data.
- **Velocity** is calculated by time integration of the acceleration (tends to accumulate large errors)

IMU Bosch BNO055 Sampling Frequencies:

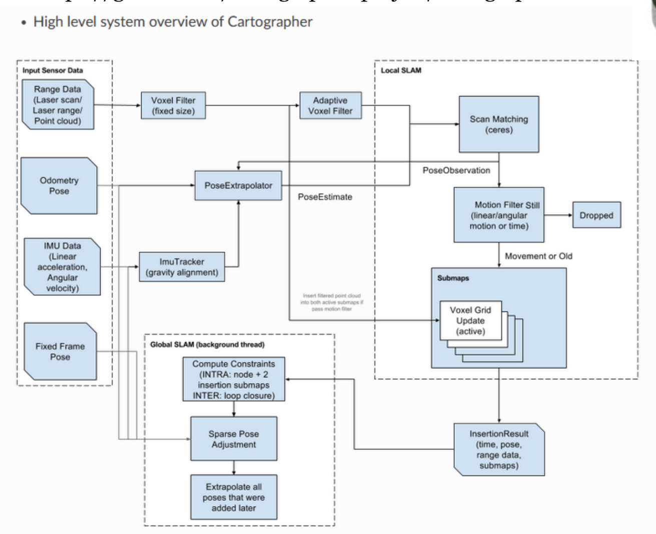
- **Accelerometer** updates: 1 KHz
- **Gyroscope** updates: 523 Hz
- **Magnetometer** updates: 30Hz

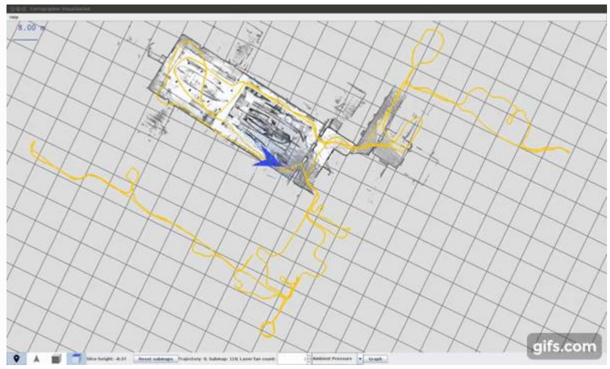


Universiteit Leiden. Bij ons leer je de wereld kennen

Cartographer

https://github.com/cartographer-project/cartographer



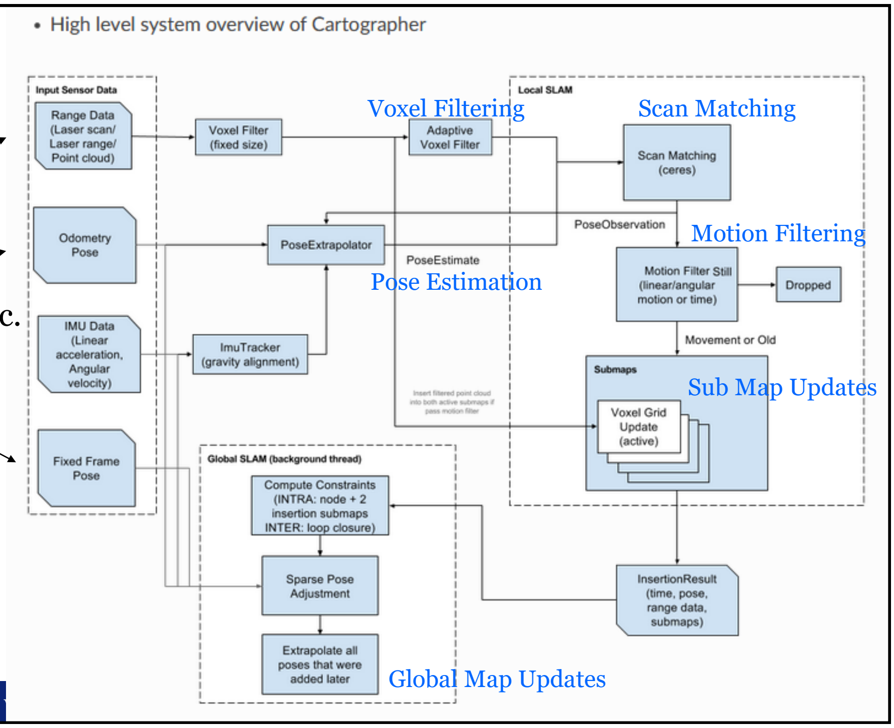


Cartographer gives real-time simultaneous localization and mapping (SLAM) in 2D and 3D.

Cartographer

https://github.com/cartographer-project/cartographer

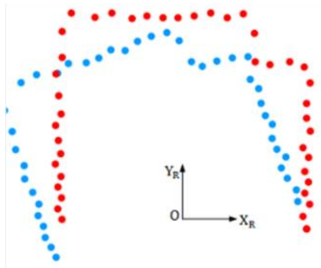
- Lidar
- Odometry
  - wheel encoders, etc.
- IMU
- Fixed Frame

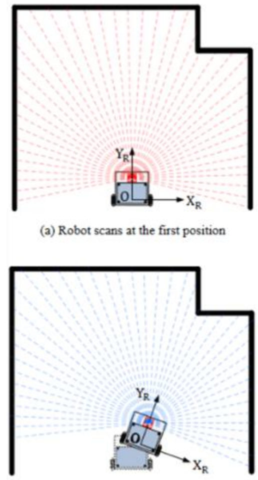


2D and 3D Lidar SLAM

Front-end:

- Matching new measurements against the current belief of the environment
- Measurements:
  - typically point clouds of lidar data
  - Movement and heading data: IMU, wheelencoders, etc.
- Filtering of the data
  - Missing or invalid data (zero length rays)
  - Noisy data: measured too far away
  - Distorted data: e.g., as a result of robot acceleration
- Transform
  - Scan matching tries to find a rigid body transform: translation and rotation
  - IMU can give heading information: more reliable than deriving it from scan matching





Riadh Dhaoui, Ruhr-Universität Bochum

2D and 3D Lidar SLAM: Scan Matching

Point to Point Matching

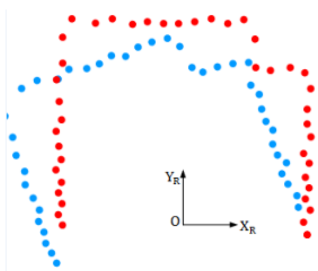
- Between the 2 scans point associations are found
- The translation from points to associated points determines a rigid body transform
- E.g found by Singular Value Decomposition (**Ceres Solver**)
- Fails in case of degenerate clouds (coplanar)
- Point association is difficult to obtain

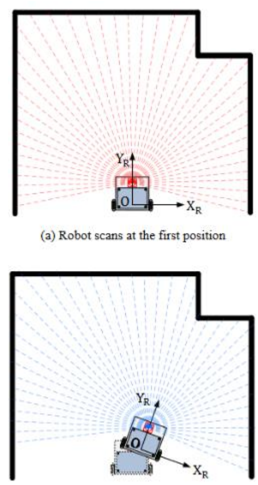
Iterative closest point (ICP) determination

Tangent Matching

Point to Grid Map

- Etc.





Riadh Dhaoui, Ruhr-Universität Bochum

Universiteit Leiden. Bij ons leer je de wereld kennen

2D and 3D Lidar SLAM: Scan Matching

Point to Point Matching

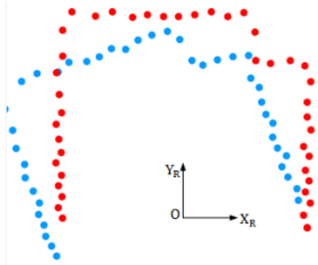
Iterative closest point (ICP) determination

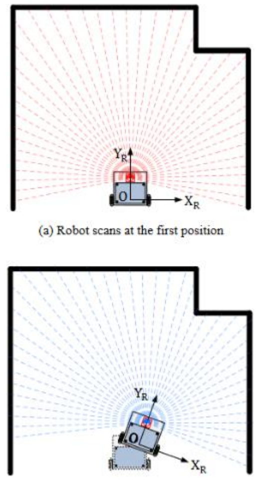
- Compute closest points
- Compute and apply the transformation
- Check if it is good enough, otherwise
  repeat for the new situation after the transformation
- Converges to local optimum

Tangent Matching

Point to Grid Map

- Etc.





(a) Robot scans at the first position

Riadh Dhaoui, Ruhr-Universität Bochum

2D and 3D Lidar SLAM: Scan Matching

Point to Point Matching

Iterative closest point (ICP) determination

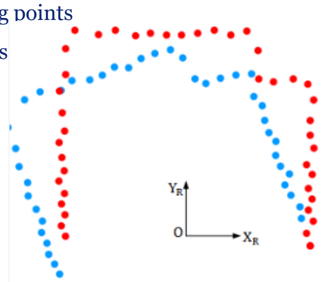
Tangent Matching

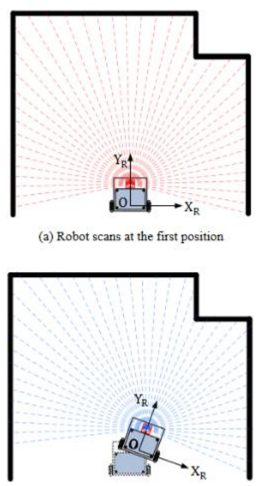
- In each of the 2 scans find Tangent lines between neighboring points
- Instead of point matching now line matching between 2 scans
- Movement and heading data from
  IMU, wheelencoders, etc. can help

Point to Grid Map

- Map the scan points to a coarser grid map and
  do matching on the grid.

Etc.





(a) Robot scans at the first position

Riadh Dhaoui, Ruhr-Universität Bochum

Universiteit Leiden. Bij ons leer je de wereld kennen

SLAM: loop closing using OverlapNet

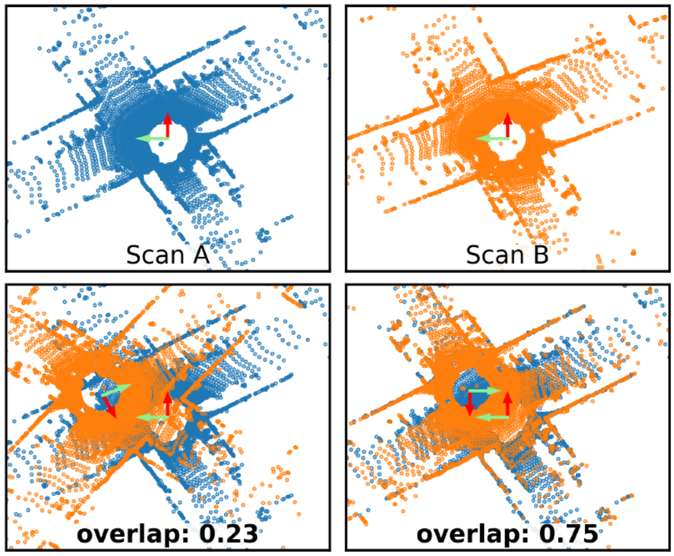
1) Pose estimation relative to recent poses: e.g. using incremental scan matching, IMU data odometry
2) Loop closing: correcting accumulated drift, maintaining consistency between measurements

Loop closure detection:

- Estimate lidar point clouds overlap (note: also used in photogrammetry):
  - Yaw transformation estimate
  - Score, e.g., using Iterative Closest Point
- Can also be used for global scan matching.

OverlapNet a DNN (2021) a method that does an estimate without transformation guessing, uses spherical projection of 3D Lidar data.

Performance on Kitty-odometry dataset.

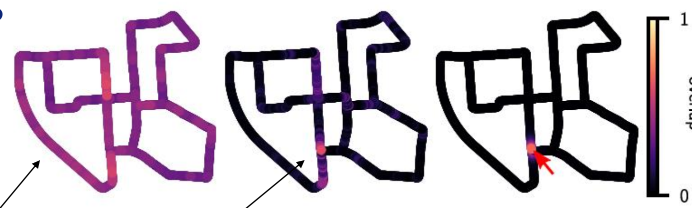


Example: Scan A and B overlap detection: scored after transformation.

Universiteit Leiden. Bij ons leer je de wereld kennen

SLAM: Loop Closing OverlapNet

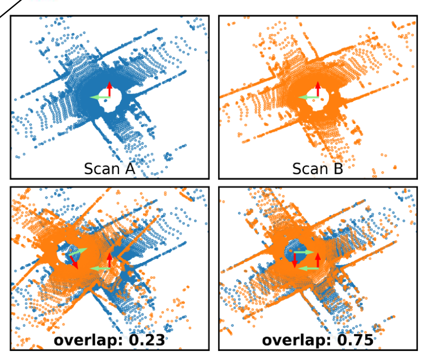
1) Pose estimation relative to recent poses: incremental scan matching, odometry
2) Loop closing: correcting accumulated drift



(a) Exhaustive evaluation of Eq. (3) (b) OverlapNet estimates (c) Ground truth

Loop closure detection:

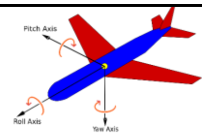
- In general overlap scores based on point-cloud differences (use Eq. 3 of X Chen et al., OverlapNet, May 2021) will be high at many locations of the map.
- OverlapNet a DNN method that does an estimate without transformation guessing, uses spherical projection of 3D Lidar data.



Example: Scan A and B overlap detection: scored after transformation.

Universiteit Leiden. Bij ons leer je de wereld kennen

OverlapNet



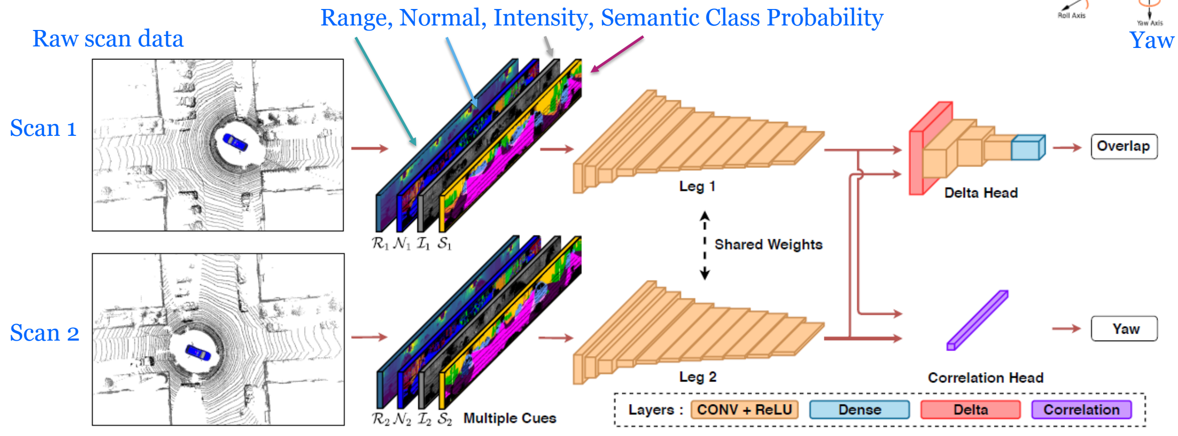


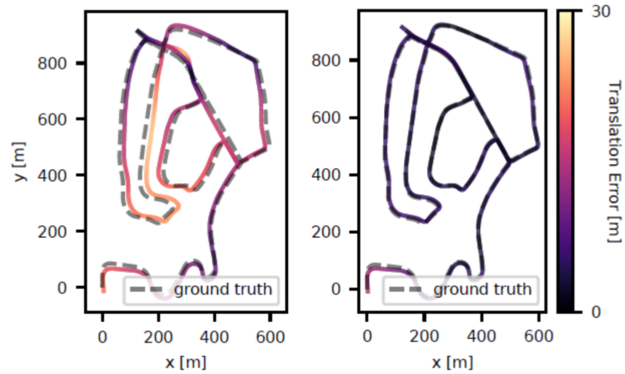
Fig. 3: Pipeline overview of our proposed approach. The left-hand side shows the preprocessing of the input data which exploits multiple cues generated from a single LiDAR scan, including range $\mathcal{R}$, normal $\mathcal{N}$, intensity $\mathcal{I}$, and semantic class probability $\mathcal{S}$ information. The right-hand side shows the proposed OverlapNet which consists of two legs sharing weights and the two heads use the same pair of feature volumes generated by the two legs. The outputs are the overlap and relative yaw angle between two LiDAR scans.

OverlapNet

X. Chen et al., OverlapNet: Loop Closing for Lidar-based SLAM, May 2021.

TABLE II: Comparison with state of the art.

Dataset	Approach	AUC	F1 score
KITTI	Histogram [26]	0.83	0.83
	M2DP [14]	0.83	0.87
	SuMa [2]	-	0.85
	Ours (AllChannel, TwoHeads)	**0.87**	**0.88**
Ford Campus	Histogram [26]	0.84	0.83
	M2DP [14]	0.84	**0.85**
	SuMa [2]	-	0.33
	Ours (GeoOnly)	**0.85**	0.84



(a) SuMa (b) Ours_CovNearestOfTop10

Fig. 6: Qualitative result on KITTI sequence 02.

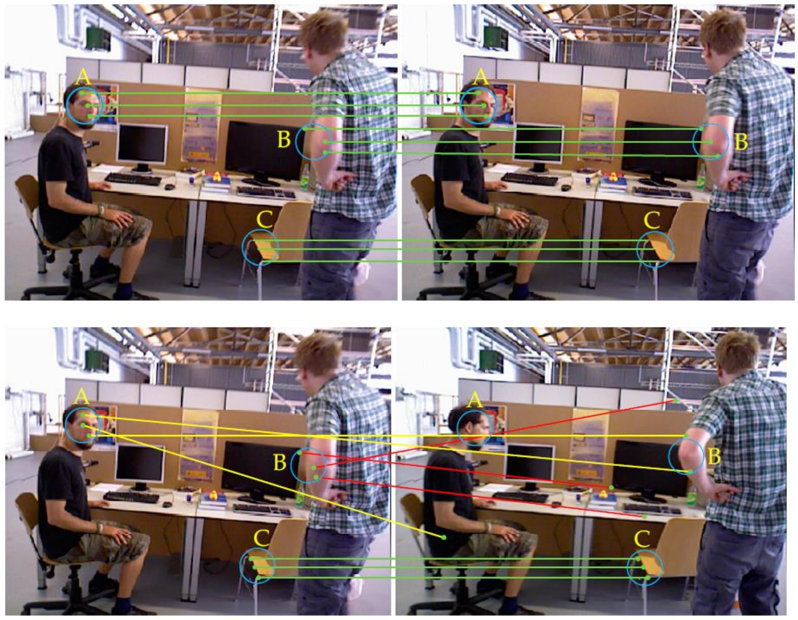
Visual SLAM

VSLAM: use camera (mono, stereo, multi-, depth, etc.) to solve SLAM

- Readily available on mobile platforms: drones, cars, mobile phones, AR/VR Glasses
- DMS-SLAM (2019), OpenVSLAM (2019)
- ORBSLAM (2015, 5979 citations in 2023, feature based (ORB) monocular SLAM system)

DMS-SLAM:

- pose tracking, closed-loop detection and relocalization based on static 3D map points of the local map
- supports monocular, stereo and RGB-D visual sensors in dynamic scenes.

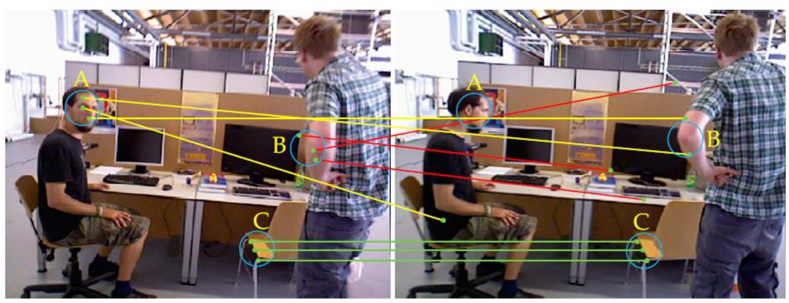


A and B partial Motion, C static => A and B matching errors, C still correct.

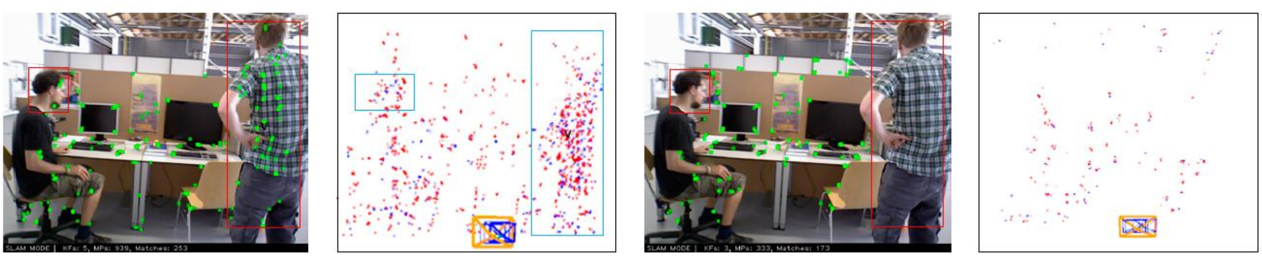
Visual SLAM

VSLAM

- use camera (mono, stereo, multi-cam, depth, etc.) to solve SLAM
- DMS-SLAM, OpenVSLAM, ORBSLAM



A and B partial Motion, C static => A and B matching errors, C still correct.



Red-boxes moving

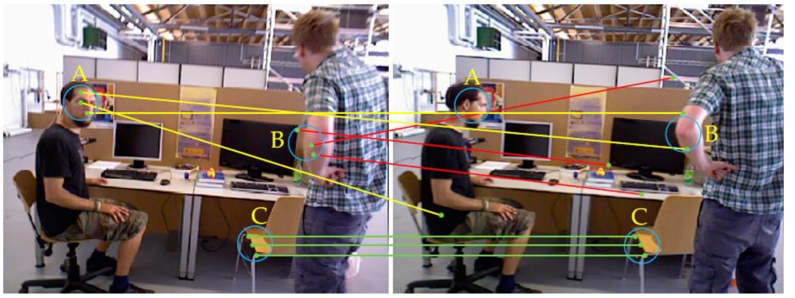
(a) (b) (c) (d)

ORB-SLAM2. DMS-SLAM

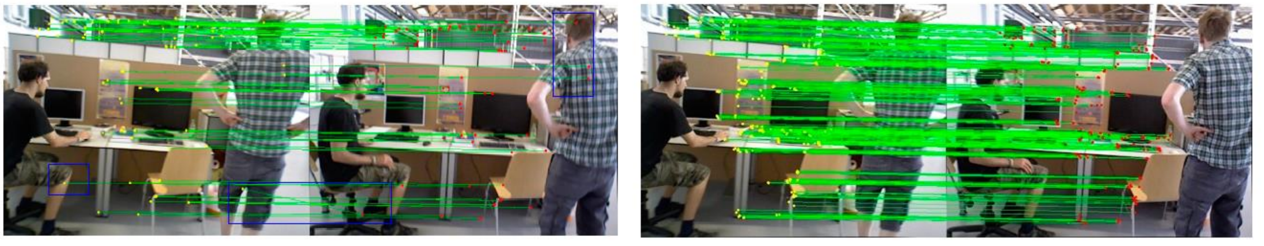
Visual SLAM

VSLAM: use camera (mono, stereo, multi-, depth, etc.) to solve SLAM

- DMS-SLAM, OpenVSLAM, ORBSLAM



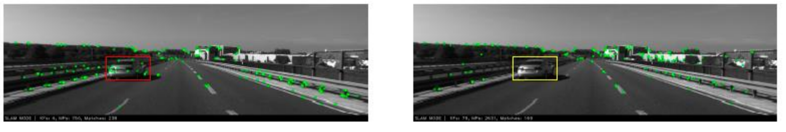
A and B partial Motion, C static => A and B matching errors, C still correct.



(a) ORB-SLAM2

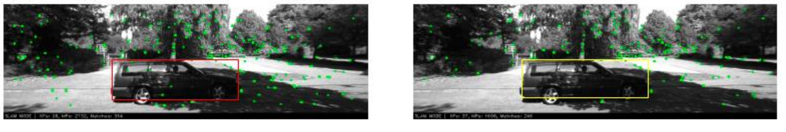
Blue-boxes wrong
feature matching point pairs.

(b) DMS-SLAM



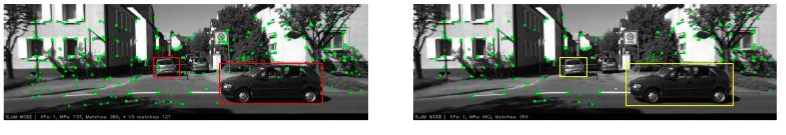
(a) ORB-SLAM2 (b) DMS-SLAM

Sequence 01



(c) ORB-SLAM2 (d) DMS-SLAM

Sequence 03



(e) ORB-SLAM2 (f) DMS-SLAM

Sequence 09

Figure 15. The pose tracking experiments of ORB-SLAM2 and DMS-SLAM on the 01, 03, 09 sequences in the KITTI dataset. The rectangular box represents the moving object in the scene, and the others are static areas.

OpenVSLAM

A Versatile Visual SLAM Framework. (S. Sumikura et al., 2019)

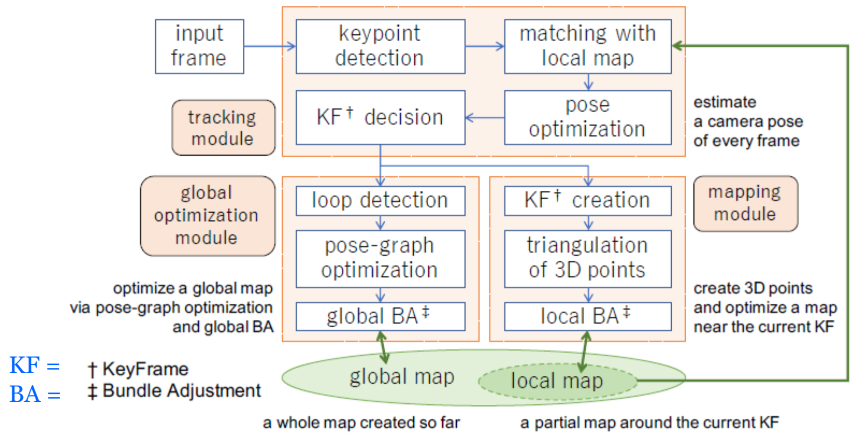
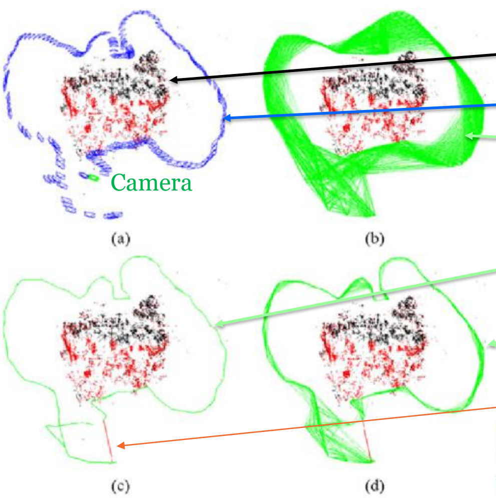


Figure 2: Main modules of OpenVSLAM: tracking, mapping, and global optimization modules.

ORB-SLAM

R Mur-Artal et al. IEEE Trans. On Robotics, Nov. 2015.



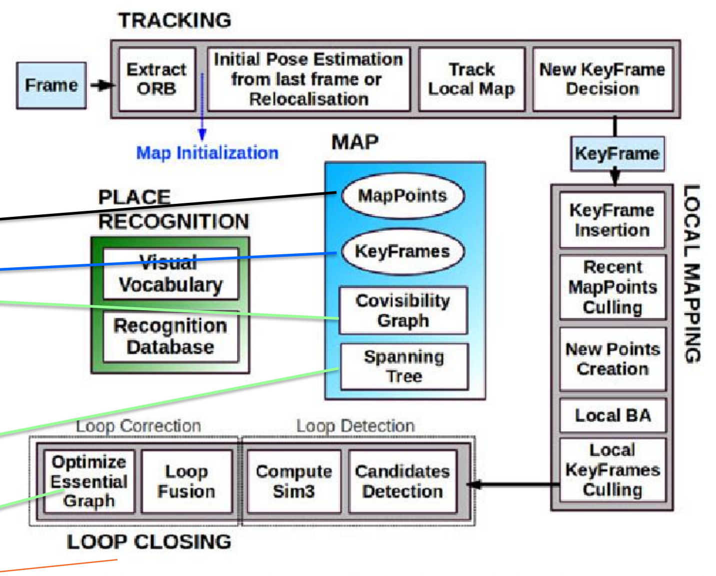
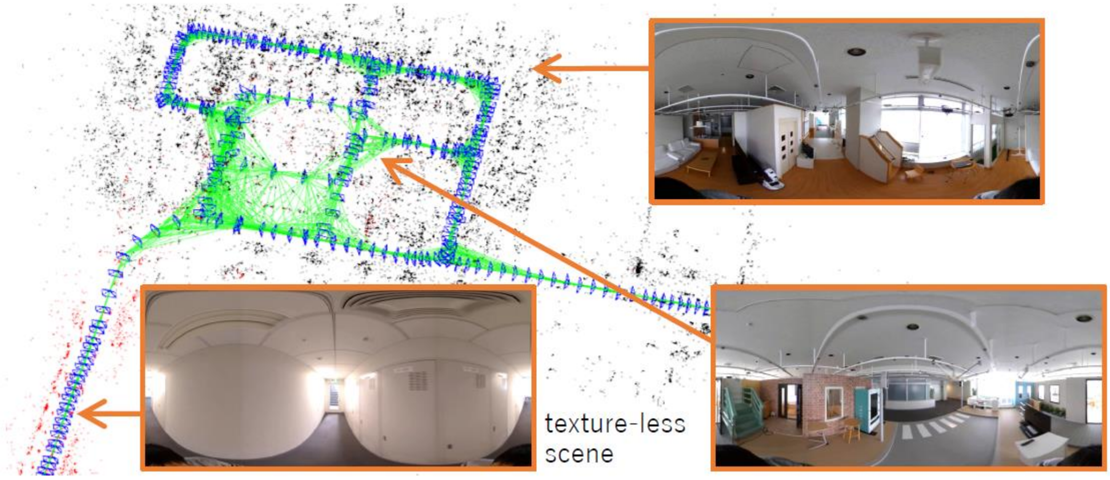


Fig. 1. ORB-SLAM system overview, showing all the steps performed by the tracking, local mapping, and loop closing threads. The main components of the place recognition module and the map are also shown.

OpenVSLAM

NB OpenVSLAM: termination of release because of concerns regarding similarities with ORB-SLAM2)
https://github.com/raulmur/ORB_SLAM2



Universiteit Leiden. Bij ons leer je de wereld kennen

Mobile Robot Challenge

Lecturer:
Dr Erwin M. Bakker (erwin@liacs.nl)
Room 126a and LIACS Media Lab (LML)

Teaching assistant:
Mor Puigventos (email)
TBA (email)

Period: February 6th - May 22nd 2023
Time: Monday 15.15 - 17.00
Place (Rooms):
a) Gorlaeus - Lecture Hall C3
b) Sylvius - 15.31
c) Van Steenis - E0.04
d) Oortgebouw - Sitterzaal

Schedule (tentative, visit regularly):

Date	Room	Subject
6-2	C2	Introduction and Overview
13-2	a	Locomotion and Inverse Kinematics
20-2	b	Robotics Sensors and Image Processing
27-2	a	No class
6-3	c	No class, SLAM Workshop on Brightspace
13-3	a	SLAM + Mobile Robot Challenge Intro
20-3	d	Project Proposals I (by students)
27-3	d	Project Proposals II (Week 13, start 15.30)
3-4	d	Robotics Vision
10-4		No Class (Eastern)
17-4	d	Robotics Reinforcement Learning&Workshop
24-4	d	Project Progress Reports
1-5	d	Mobile Robot Challenge I
8-5	a	Mobile Robot Challenge II
15-5	d	Project Demos I
22-5	d	Project Demos II
29-5		Whit Monday
5-6		Project Deliverables

Website: http://liacs.leidenuniv.nl/~bakkerem2/robotics/

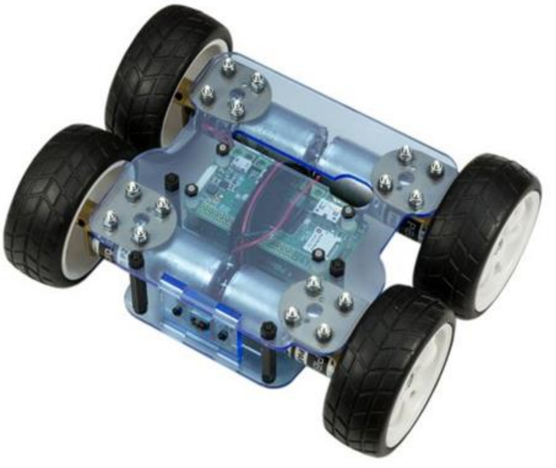
Group Size 4 students

Universiteit Leiden. Bij ons leer je de wereld kennen

Mobile Robot Challenge Introduction

YetiBorg

- Raspberry Pi Zero W
- 4 motors
- 1 Camera
- No odometry

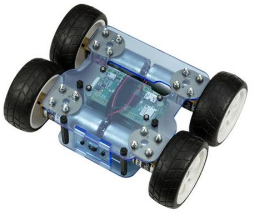


- Programming and control through SSH
- Python and OpenCV
- No live camera footage from the YetiBorg
- VNC can be used to get live camera footage

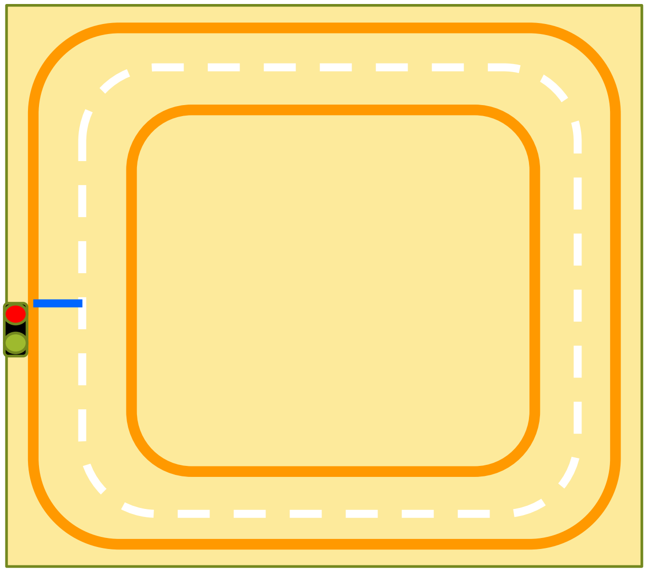
Universiteit Leiden. Bij ons leer je de wereld kennen

YetiBorg URBAN Challenge (previously: 2021)

Urban Challenge
- Keep right
- Traffic Lights
- Traffic Signs
- Obstacles



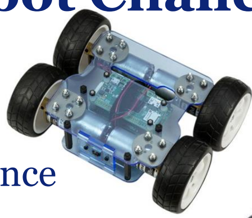
Qualification Track
- Keep Right
- Traffic Lights
- Stop as close as possible before the blue line

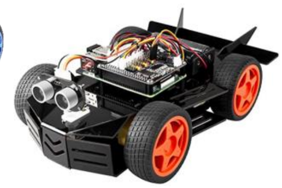
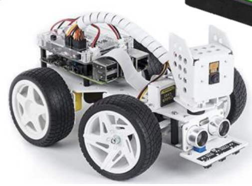
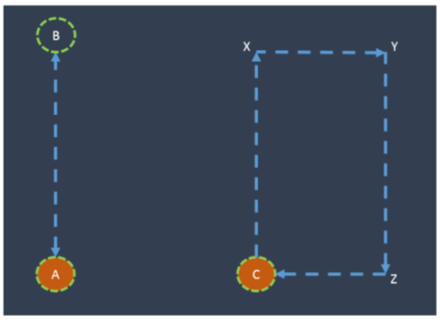


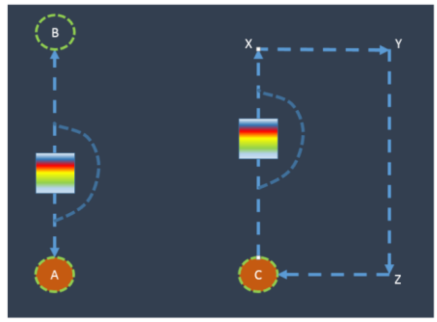
Universiteit Leiden. Bij ons leer je de wereld kennen

Mobile Robot Challenge (previously: 2022)

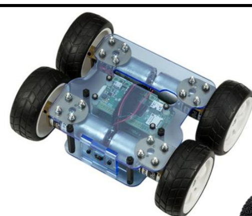
Challenge
- Repeatability
- Obstacle avoidance





Mobile Robot Challenge 2023


- Unknown object: detection and distance
  - Object typically ~7cm x 7 cm x 7cm, and clearly visible
  - Robot is placed on the floor and switched in active mode
  - Object is placed ~1m in front of the robot
    => distance (in cm) should be reported
  - Object is placed somewhat further or closer
    => distance should be reported and robot drives towards object and stops as close as possible to the object.
- Unknown object avoidance
- Unknown object search in 2.5m x 2.5 m area

Mobile Robot Challenge Teams

- Mobile Robot Challenge Teams of 4 members.
- Team Name and 1 contact person.

Robots will be handed over to a Team Representative
on Friday March 17th at 13.30
in the lobby of the Snellius building.

Challenge will be available at that day also.

Universiteit Leiden. Bij ons leer je de wereld kennen

Robotics Project Proposals Presentations

Monday 20-3 and 27-3 2023

Present your Robotics Project Proposal during a **5 minute (max)** talk. Clearly state the title of your project, the team members, your goals, how you will pursue them, what are the challenges and what at least can and should be delivered on the demo day on May 15th and May 22rd 2023.

Note: Groups of 1-5 members are allowed.
Each student: submit your project group before Friday 17-3 to Brightspace
(available 14-3)

The presentation should contain 5 slides:

1. Title and group members.
2. Goal of the project.
3. How will you pursue these goals: **division of work per group member**
4. What are the challenges.
5. What at least can and should be delivered on the demo days on May 15th and May 22nd 2022.

The LIACS Media Lab can support your project with some materials for your project. Please clearly state any materials that you would need for your proposal. Note that these materials are limited so project goals may need to be adjusted accordingly.
Each presentation will be followed by a short class discussion.

Universiteit Leiden. Bij ons leer je de wereld kennen